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LEACHING REQUIREMENT FOR SALINITY CONTROL
III. BARLEY, COWPEA, AND CELERY

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ABSTRACT

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Leaching requirement, the smallest steady-state leaching fraction which prevents any loss in crop yield, was determined for barley, cowpea, and celery in field plots at the U.S. Salinity Laboratory. Six replicated leaching-fraction treatments were irrigated many times each day with small quantities of water having an electrical conductivity of 2.3 dS/m. The crops were grown in succession between January 1979 and September 1981.

The leaching requirement (L_r) was 0.10 for barley grain and 0.13 for barley forage. For cowpea seed, L_r was 0.16; 0.17 for cowpea forage. L_r for celery was 0.14. These experimentally determined values for barley and cowpea seed are higher by about 0.05 than those predicted by a leaching-requirement model based on an exponential crop water-uptake pattern. The experimental values for celery and cowpea forage are lower than predicted values by 0.06. These differences are not considered significant, however, when considered in terms of the small differences in water applications (about 25 mm) to cause these changes in L_r. Evapotranspiration during each crop's growing season coincident with L_r was 410, 630, and 460 mm for barley, cowpea, and celery, respectively.

INTRODUCTION

Increasing levels of salinity, both in cultivated soils and in irrigation water, are becoming widespread throughout the world. Unless water management practices are established to ensure leaching, soil salinity will become excessive and crop production will decline. That portion of the applied (irrigation plus rainfall) water that percolates below the crop root zone is termed the leaching fraction. The smallest leaching fraction which prevents any loss in crop yield, has been termed the leaching requirement (L_r). Thus, loss in crop production because of excess salinity can be prevented if the leaching requirement is achieved or surpassed. Initially, L_r's were established for wheat, sorghum, and lettuce grown in rotation with an irrigation water having an electrical conductivity of 2.2 dS/m (Hoffman et al., 1979). In a second study, the L_r's for oat,

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tomato, and cauliflower were determined (Jobes et al., 1981). Here, we report the L_r's for barley, cowpea, and celery determined from measurements of crop yield, soil salinity, and water balance.

The results of the first two experiments confirmed the predictions of the leaching requirement model proposed by Hoffman and Van Genuchten (1982). Nevertheless, further confirmation is required before this generalized model, presented in terms of the crop salt tolerance threshold (Maas and Hoffman, 1977) and the salinity of the applied water, can be recommended without reservation. Thus, the experiments were continued for two additional years with only a change in crops.

EXPERIMENTAL PROCEDURE

The experimental design was similar to that reported by Hoffman et al. (1979). Only pertinent details and changes in experimental procedure are presented here. The treatments consisted of six replicated leaching fractions (L's) of 0.17, 0.13, 0.09, 0.07, 0.04, and 0.02, selected to span the range at which initial depressions of yield were anticipated. Because celery was expected to be salt sensitive, the highest L was increased to about 0.20 during the celery season.

An annual crop rotation of barley (*Hordeum vulgaris*, cv. California Mariout 67), cowpea (*Vigna unguiculata*, cv. California Blackeye No. 5), and celery (*Apium graviolens* var. Dulce, cv. Tall Utah 52-7OR) was grown at the U.S. Salinity Laboratory in field plots where various leaching fractions were maintained over long periods of time with small, frequent irrigations. These crops were selected because of their importance in irrigated regions where salinity is a hazard and their suitability for an annual crop rotation. Barley was sown in late January 1979 and harvested at the beginning of June. Data from the tomato crop which followed barley was included in a previous paper (Jobes et al., 1981). Celery seedlings, obtained from a commerical nursery, were transplanted into the plots the first of October and were harvested before maturity in mid-January 1980 so the 1980 barley crop could be sown on schedule. Barley was harvested in late May. Cowpea was planted in mid-June and harvested in mid-September, followed by celery which was harvested in mid-February 1981 at maturity. After an intervening turnip crop, cowpea was planted the beginning of June and harvested the beginning of September 1981. Thus, each crop reported was grown twice with some other crops in the rotation. Barley seed, spaced on seed tape at intervals of 10 mm, was sown at a depth of 10 mm in rows 22.5 cm apart. Cowpea and celery seedlings were at intervals of 28 cm in rows 45 cm apart.

All 12 plots were irrigated with water having a total salt concentration of 1350 g/m^3, an electrical conductivity of 2.3 dS/m, and an osmotic potential of −90 J/kg. The amounts of solutes in the irrigation water (mol/m^3) were: Ca, 4.6; Mg, 1.9; Na, 10.8; K, 0.1; CO_3 + HCO_3, 3.1; Cl, 7.8; SO_4, 4.9; and NO_3, 2.6. The pH of the water was 7.6 and the sodium-adsorption-ratio was

4.3 $(mol/m^3)^{1/2}$. Rainfall was excluded by placing reinforced plastic covers over the plots during rain storms.

Nitrogen fertilizer as calcium nitrate was added continuously to the irrigation water. The application rate for barley ranged from 120 to 240 kg N/ha as L increased from 0.02 to 0.17. The application rate ranged from 70 to 120 kg N/ha for cowpea and 100 to 160 kg N/ha for celery. Before each celery crop, phosphorus as superphosphate was applied to the soil surface at a rate of 170 kg/ha before cultivating to a depth of 15 cm. Differences in these fertilizer application rates, however, should not cause yield differences. The level of salinity in the root zone has been shown to have little influence on leaf concentration of either nitrogen or phosphorus of many crops (Bernstein et al., 1974). Plants, reduced in growth as a result of soil salinity imposed by reduced leaching, require less nutrients. In addition, the lack of significant differences in the relatively large concentrations of nitrate in the drainage waters among leaching treatments (Hoffman et al., 1979) also indicates adequate fertility.

The irrigation system (described in Hoffman et al., 1979) passed frequently over each plot and applied water to the soil through vertical tubes midway between every second row of barley and 10 cm to one side of each row of cowpea and celery. The system applied 0.2-mm depth of water each irrigation pass, based on the total surface area of the plot. Thus, if the required irrigation depth was 5 mm for a given day, the system made 25 passes.

Leaching fractions were controlled by maintaining the desired ratio between the depths of drainage water (D_d) and the depth of irrigation water (D_i) (i.e., $L = D_d/D_i$). Drainage was assumed to be equivalent to the leachate collected from a suction lysimeter, 80 × 45 × 60 cm deep, in each plot. The suction in the ceramic drain tubes at the bottom of the lysimeter was maintained continuously at −3 m. Irrigation and drainage water volumes were measured twice weekly, and the amount of irrigation was adjusted to maintain the desired value of L.

Soil matric potential was monitored in each plot at two locations with tensiometers at depths of 10, 40, and 60 cm. Soil salinity was monitored in three leaching treatments (0.02, 0.07, and 0.17) with salinity sensors at depths of 20 and 40 cm. After each crop harvest, during both cowpea crops, and during the 1980 celery season, the soil was sampled to a depth of 1.4 m and analyzed for electrical conductivity, chloride concentration, and water content. Samples of irrigation and drainage waters were analyzed periodically for individual ion concentrations.

At harvest, seed and total shoot dry weights were measured for barley and cowpea. For celery, the fresh weights of the marketable bunch and total shoot were determined. Representative samples of barley grain from the 1980 crop were analyzed for percentage of solids, starch, sugar, fat, fiber, ash, and nitrogen. Differences in milling properties of barley were also evaluated by measuring the percentage of husks removed, cracked grain, and decortication.

After milling, the bran and decort were each analyzed for percentage of starch and sodium. The only quality check performed on cowpea was the determination of the average mass of a seed on the 1981 crop. Various quality parameters were measured on 20 celery plants from each plot in the 1980—81 crop. Measurements consisted of plant height, length and number of marketable petioles, and the number of side shoots per plant. The average-size petiole from each of these 20 plants was measured for mid-petiole width and thickness and then evaluated for pith and the wing, mid-section, and first node. Pith, a breakdown of parenchyma cells which leaves air spaces in the tissue, was rated on a scale from 0 (no pith) to 3 (severe pith).

The values of L_r determined experimentally for each crop were compared with values predicted by the model of Hoffman and Van Genuchten (1982). This model, based upon an exponential crop water-uptake pattern, predicts L_r from the salinity of the applied water and the salt tolerance threshold of the crop (Maas and Hoffman, 1977).

RESULTS

Leaching fractions

This experiment was a continuation of a 6-year study; the same water quality and method of irrigation were used, thus quasi-steady-state conditions

TABLE I

Irrigation and drainage depths measured for each crop as a function of leaching-fraction treatment

Year	Irrigation depth (D_i) for indicated leaching-fraction treatment (mm)						Drainage depth (D_d) for indicated leaching-fraction treatment (mm)					
	0.17	0.13	0.09	0.07	0.04	0.02	0.17	0.13	0.09	0.07	0.04	0.02
Barley												
1979	591	445	461	342	351	348	106	69	43	36	18	3
1980	648	527	454	361	321	278	125	72	45	29	17	6
Mean	620	486	458	352	336	313	116	70	44	38	18	4
Cowpea												
1980	684	584	564	456	384	398	111	86	44	34	16	7
1981	912	753	646	607	482	466	156	104	53	46	21	10
Mean	798	668	605	532	433	432	134	95	48	40	18	8
Celery												
1979	380	423	316	321	305	273	79	54	28	26	16	4
1980	625	519	471	389	326	299	124	72	41	34	16	7

for soil salinity had been reached before this experiment began. Nevertheless, any failure to alter irrigation management to compensate for changes in crop water requirements influenced soil salinity and leaching within a few days, depending on the magnitude of the change. Thus, the desired L treatments could not be maintained precisely. The results are therefore reported in terms of actual L's attained during each crop.

Table I gives the total depths of irrigation and drainage for each crop as a function of the leaching treatment. The amounts are reported as the equivalent depth of water applied uniformly over the entire surface area of a plot (18.23 m^2). As expected, irrigation and drainage depths were greatest for cowpea which was grown in the summer when evaporative demand is high. The irrigation and drainage depths for all three crops are higher the second year than the first. During the barley crop, pan evaporation, and therefore evaporative demand, was higher in 1980 than in 1979 for each month except

TABLE II

Leaching fraction by crop computed as the ratio of water depths (D_d/D_i), chloride concentration (Cl_i/Cl_d), and total salt concentration (σ_i/σ_d) of the irrigation and drainage waters

Year	Computation method	Leaching fraction for indicated leaching-fraction treatment					
		0.17	0.13	0.09	0.07	0.04	0.02
Barley							
1979	D_d/D_i	0.18	0.16	0.09	0.11	0.05	0.01
	Cl_i/Cl_d	0.15	0.09	0.05	0.06	0.03	0.02
	σ_i/σ_d	0.30	0.24	0.18	0.17	0.12	0.09
1980	D_d/D_i	0.19	0.14	0.10	0.11	0.05	0.02
	Cl_i/Cl_d	0.20	0.10	0.10	0.07	0.03	0.02
	σ_i/σ_d	0.44	0.27	0.24	0.19	0.13	0.09
Cowpea							
1980	D_d/D_i	0.16	0.15	0.08	0.07	0.04	0.02
	Cl_i/Cl_d	0.16	0.10	0.08	0.06	0.04	0.03
	σ_i/σ_d	0.39	0.26	0.22	0.18	0.13	0.08
1981	D_d/D_i	0.17	0.14	0.08	0.08	0.04	0.02
	Cl_i/Cl_d	0.15	0.12	0.08	0.07	0.04	0.02
	σ_i/σ_d	0.38	0.30	0.21	0.20	0.12	0.08
Celery							
1979	D_d/D_i	0.20	0.14	0.09	0.09	0.05	0.02
	Cl_i/Cl_d	0.14	0.11	0.09	0.06	0.03	0.02
	σ_i/σ_d	0.37	0.27	0.24	0.19	0.12	0.08
1980	D_d/D_i	0.20	0.14	0.09	0.09	0.05	0.02
	Cl_i/Cl_d	0.16	0.14	0.09	0.07	0.04	0.02
	σ_i/σ_d	0.38	0.30	0.22	0.18	0.13	0.09

May. The same was true in 1981 compared to 1980 for the cowpea crop. Allowing the celery to mature in 1980 (20-week season) compared to a short season in 1979 (15 weeks) accounts for the larger depths and negates the meaning of average values.

The leaching fraction (L), calculated as the ratio of the depths of drainage and irrigation (D_d/D_i) for each leaching treatment are given in Table II. The measured L's are in close agreement with the desired values throughout the experiment. Leaching fraction was also calculated as the ratio of the chloride concentration (Cl) in the irrigation and drainage waters (Cl_i/Cl_d) (Table II). The L's based on Cl ratio are very close to those based on water balance. L's calculated from measures of electrical conductivity (σ_i/σ_d) were consistently higher than those based on chloride (Table II). As reported earlier, ratios of electrical conductivity overestimate L unless corrections are made for salt precipitation and nitrogen loss (Hoffman et al., 1979).

YIELDS

Crop production is summarized in Table III as a function of the L treatment for two cropping seasons. Barley yield is reported as grain dry weight, cowpea as seed dry weight, and celery as fresh weight of marketable bunches. The total shoot growth is also given for each crop. The dry weight of total growth is taken as forage for barley and cowpea.

Barley yield at the higher L's (5.2 Mg/ha) are well above average commercial yields in California (3.2 Mg/ha) (USDA, 1980). Dry seed yields of cowpea at the 0.17-L treatment (3.2 Mg/ha) were slightly higher than average yields (3.0 Mg/ha) from the nonsaline treatment of a salt tolerance experiment performed simultaneously in adjacent field plots (West and Francois, 1982) and well above average commercial yields (1.6 Mg/ha) (Sallee and Smith, 1969). Total shoot growth of cowpea was also slightly higher in the highest L treatment than in the control treatment of West and Francois (8.0 vs 7.0 Mg/ha). The most desirable commercial size for a celery bunch is between 0.9 and 1.1 kg (H. Johnson, University of California, Riverside, personal communication, 1980). Yields from the 0.17-, 0.13- and 0.09-L treatments in 1980 were 1.05, 0.95, and 0.95 kg per bunch, respectively; quite acceptable for marketing. An average bunch weight of 1.05 kg is equivalent to a yield of 78 Mg/ha, average commercial production in the U.S. is less than 55 Mg/ha (USDA, 1980). The average bunch weight for celery grown in a nonsaline treatment simultaneously and in adjacent field plots was 0.83 kg (Francois and West, 1982). Based on these comparisons, we conclude that yields from the 0.17-L treatments were maximal for the experimental growing conditions and neither better water quality nor more leaching would have increased yields significantly.

Fig. 1 gives the relative crop yield as a function of measured L. The minimum L consistent with maximum crop production (L_r) for barley grain was about 0.10, based on linear regression analysis of data below this L. The last significant difference (LSD given in Table III) indicates that grain yield

TABLE III

Crop production as a function of leaching-fraction treatment for barley, cowpea, and celery

Year	Yield[a] for indicated leaching-fraction treatment							Total shoot growth for indicated leaching-fraction treatment						
	0.17	0.13	0.09	0.07	0.04	0.02	LSD[b]	0.17	0.13	0.09	0.07	0.04	0.02	LSD
Barley (g/m^2, dry weight)														
1979	514	550	528	528	459	375		1170	1112	1010	970	834	672	
1980	438	507	513	498	438	367		1114	1171	1128	982	807	644	
Mean	476a	529a	521a	513a	448ab	371b	79	1142a	1142a	1069a	976ab	820bc	658c	163
Cowpea (g/m^2, dry weight)														
1980	297	272	245	193	132	118		772	676	595	440	296	292	
1981	342	284	244	220	154	104		822	639	546	481	295	213	
Mean	320a	278a	244b	206c	143d	111d	38	797a	657b	570c	460d	296e	252e	86
Celery (g/plant, fresh weight)														
1979[c]	410a	422a	350ab	270ab	271ab	234b	162	550a	565a	522a	402a	414a	374a	206
1980	1052a	950a	948a	608b	444bc	328c	244	1526a	1418a	1385a	1006b	707bc	549c	369

[a]Yield *for* barley is *grain*; for cowpea it is seed; and for celery it is the bunch (the marketable stalks).
[b]Least significant difference at 5% confidence level. Letters within rows indicate significant differences at the 5% level with Duncan's multiple range test.
[c]Plants were immature at harvest.

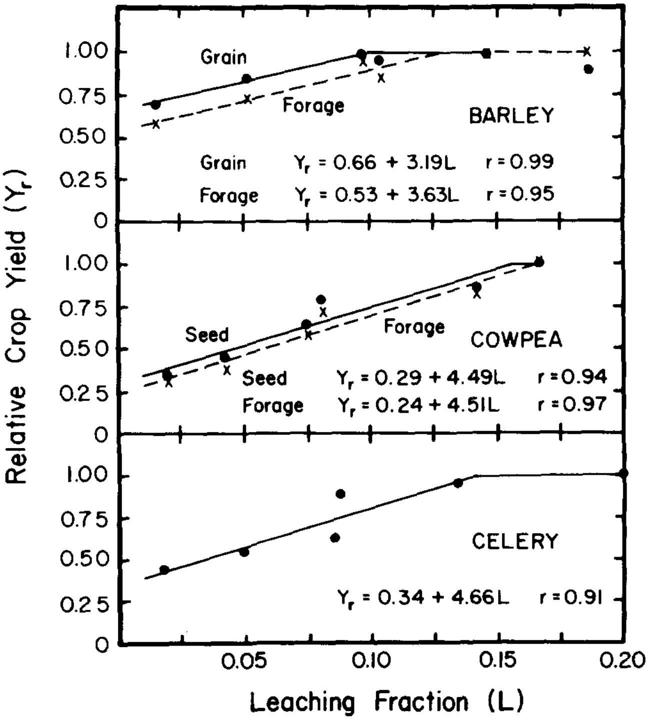

Fig. 1. Influence of leaching fraction on relative crop yield for barley, cowpea, and celery with an irrigation water quality of 2.3 dS/m. The linear equations apply to the portion of the curves where the relative yield is reduced below 1.0.

at an L of 0.05 (0.04-L treatment) was significantly less than that at an L of 0.095 (0.09-L treatment). Thus, the L_r for barley grain is 0.10. Barley, like oat (Jobes et al., 1981), shows a trend to lower grain production for an L treatment above the L_r. For barley forage, yield decreases linearly below an apparent L_r of 0.13, although forage yield was not significantly below that of the 0.17-L treatment until the L dropped below 0.10. Barley forage, like oat forage (Jobes et al., 1981), was more sensitive to L than grain.

The L_r, based on linear regression analysis, was 0.16 for cowpea seed and 0.17 for cowpea forage. The LSD indicates a significant seed yield and total shoot growth reduction for cowpea between an L of 0.17 and 0.14. As noted above, neither less saline irrigation water nor increased leaching would have increased seed or total shoot growth above that at L = 0.17. Cowpea forage was slightly more sensitive to L than seed.

The L_r for celery was 0.14. The linear analysis of each year's data separately are in agreement; the L_r was about 0.14 even though the relative yield reductions in 1980 at low L's were greater than in 1979. Analysis of total shoot growth also lead to the same L_1.

Yield quality

Leaching fraction had no significant effect on any of the constituents of barley grain that were measured. The average percentages of solids, starch, sugar, fat, fiber, ash, and nitrogen were 90.4, 44.8, 3.1, 1.3, 6.1, 2.4, and 2.3, respectively. Likewise, *L* did not influence milling properties. A 5-min milling period removed 82% of the husks and decorted 89% of the grain, only 11% of the grain was damaged during dehusking. The barley bran contained 26.1% starch and 0.09% sodium while the decort was 52.8% starch and 0.03% sodium.

The average mass of a cowpea seed for *L* treatments above 0.07 was 228 mg. Seed mass was reduced significantly for *L*'s below 0.07 and averaged 209 mg for an *L* of 0.02. Thus, the influence of *L* on yield was dominated by the number of seeds harvested, not the average seed mass. West and Francois (1982) reported an average seed mass for their nonsaline treatment of 225 mg in 1981 and seed mass was not reduced by soil salinity. West and Francois also attributed yield reduction induced by soil salinity to the number of seeds, not seed mass. These results were similar to those for tomato (Jobes et al., 1981), where *L* reduced fruit number more than fruit size.

The influence of leaching fraction on the quality of celery (Table IV) follows closely the influence of *L* on yield with the exception that the number of side shoots was not affected. Plant height and petiole width were not reduced significantly until *L* was less than 0.13. An *L* of less than 0.09 was required to reduce petiole length or thickness and the number of mature petioles per plant. Average petiole length was longer than the 18-cm length required for U.S. Extra No. 1 grade celery for *L* treatments of more than 0.04. The pitch rating indicated that the higher *L* treatments should have been harvested earlier for best quality.

TABLE IV

Quality parameters for the 1980—81 celery crop as a function of leaching-fraction treatment

Harvest quality parameter	Leaching fraction treatment						
	0.17	0.13	0.09	0.07	0.04	0.02	LSD[a]
Plant height (cm)	64a	63a	61b	56c	47d	44e	2.0
Number of mature petioles per plant	8.8a	8.0bc	8.6ab	7.8c	6.9d	6.9d	0.6
Number of side shoots per plant	3.8a	4.4a	3.9a	3.9a	4.2a	3.9a	0.9
Petiole length (cm)	24a	24a	24a	22b	19c	17d	1.0
Petiole width (mm)	28a	27a	25b	22c	19d	17e	1.4
Petiole thickness (mm)	9.2a	9.2a	8.7a	7.9b	6.6c	5.9d	0.5
Pith rating[b]	1.0a	0.6bc	0.8ab	0.6c	0.2d	0.5c	0.2

[a]Least significant difference at the 5% probability level. Letters within rows indicate significant differences at the 5% level with Duncan's multiple range test.
[b]Rating of pith development in the petioles; scaled from 0 for no pith to 3 for severe pith.

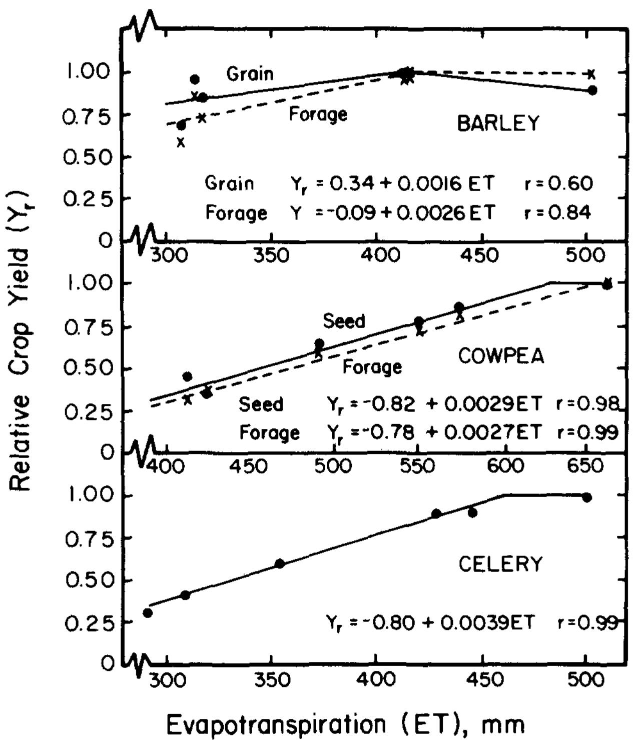

Fig. 2. Relative yield of barley, cowpea, and celery as a function of evapotranspiration. The linear equation applies to the left portion of the curve where relative yield is reduced below 1.0. Data for celery are from 1980 only.

Water use

Evapotranspiration (ET) for each L treatment can be calculated as the difference between the values of D_i and D_d given in Table I. These calculated values of ET are shown as a function of relative crop yield in Fig. 2. Neither grain nor forage yield of barley was increased above an ET of 410 mm. Barley was similar to the other grain crops grown at the same time of year in this series of experiments with respect to the lowest ET consistent with full production (440 mm for wheat, 390 mm for oat, and now 410 mm for barley). For cowpea, seed yield did not increase above an ET of 630 mm but forage production continued to increase to an ET of 660 mm. The other crops grown during the summer, sorghum and tomato, had minimum ET values for full production of 550 and 850 mm, respectively. The differences are not surprising considering the large variation in physiology and morphology. Celery yield did not increase above an ET of 460 mm. ET for this fall crop is well above that of the other two fall crops studied (cauliflower, 230 mm, and lettuce, 245 mm). The larger ET for celery was probably caused, at least in part, by the longer growing season. As leaching was reduced from 0.17 to 0.02, ET was reduced 39%

for barley, 36% for cowpea, and 41% for the 1980 celery crop. These values fall within the range of reduction (15 to 50%) reported previously for other crops (Hoffman et al., 1979; Jobes et al., 1981).

Pan evaporation (E_p) during the two seasons of barley and cowpea and the 1980 celery crop averaged 476, 780, and 536 mm, respectively. The average pan factor (ET/E_p) for each crop for the minimum ET without yield reduction (see Fig. 2) was 0.86 for barley, 0.81 for cowpea, and 1.03 for celery. Comparable pan factors for previous crops studied were 0.60 for oat, 0.78 for cauliflower, more than 0.81 for tomato, 0.61 for wheat, 0.58 for sorghum, and more than 0.48 for lettuce. Thus, there is not a unique pan factor which will assure adequate leaching (full crop production) for all crops. The value may be as low as 0.6 as for several crops or more than 1.0 for others.

In previous studies, measurements of soil water content were always made about a week after each crop was harvested. As a consequence, soil water content was reported to increase with depth for the initial 10 to 20 cm of soil depth before reaching a relatively uniform value through the remainder of the profile. In Fig. 3 comparisons are given for average water contents determined during the season compared to average values taken after harvest. During the season water contents in the upper soil profile are significantly higher than those taken after harvest because the plots were irrigated many times daily.

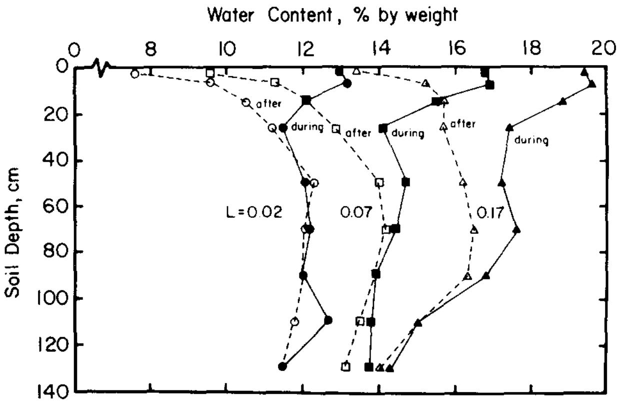

Fig. 3. Soil water contents through the soil profile during the cropping season compared to values after harvest for the 0.02, 0.07, and 0.17 leaching treatments.

For the first 5-cm soil depth interval, water contents were about 6% higher during the season than after harvest. The difference in water contents decreased with soil depth but the depth at which measurements were comparable changed with leaching fraction. For 2% leaching, values were comparable below a depth of 40 cm but comparability was not reached until a depth of 1 m for 17% leaching. These results emphasize the significance of evaporation and downward movement after irrigation ceased at harvest on the water content profile.

Soil matric potential during the six cropping periods remained reasonably stable. For the high leaching treatment, matric potential dropped from an average of —12 J/kg at a depth of 10 cm to —18 J/kg at 60 cm. For low leaching, matric potential dropped from —17 to —23 J/kg with depth. A tensiometer within each lysimeter at a depth of 40 cm averaged —14 J/kg for high leaching and —18 J/kg for low leaching.

Soil salinity

The suction lysimeters intercept only a small part of the drain water from the plots; thus, their L (given in Table II) may not be the same as the average for the plot. To check on this possibility, the leaching fraction was calculated from chloride concentrations determined from soil samples taken at several locations throughout the plot following each crop. The average chloride values from soil samples taken below the 60-cm soil depth (see Fig. 4) were 46, 99, and 358 mol/m^3 for the L treatments of 0.17, 0.07, and 0.02, respectively. L's calculated from Cl_i/Cl_d using these values for Cl_d are 0.17, 0.08, and 0.02 for the three sampled leaching treatments, respectively. These correspond to average values of 0.18, 0.09, 0.02 for D_d/D_i and 0.16, 0.08, and 0.02 for Cl_i/Cl_d where Cl_d is a volume-weighted average of drainage samples taken from the suction lysimeters in each plot (see Table II). Obviously, measurements of L from the suction lysimeters are indicative of the entire plot.

The pattern of chloride concentrations for the 0.17, 0.07, 0.02 leaching treatments is illustrated in Fig. 4. The chloride concentrations are the average values from beneath the water source, in the crop row, and midway between water sources. The patterns of accumulation are very similar, with a pocket

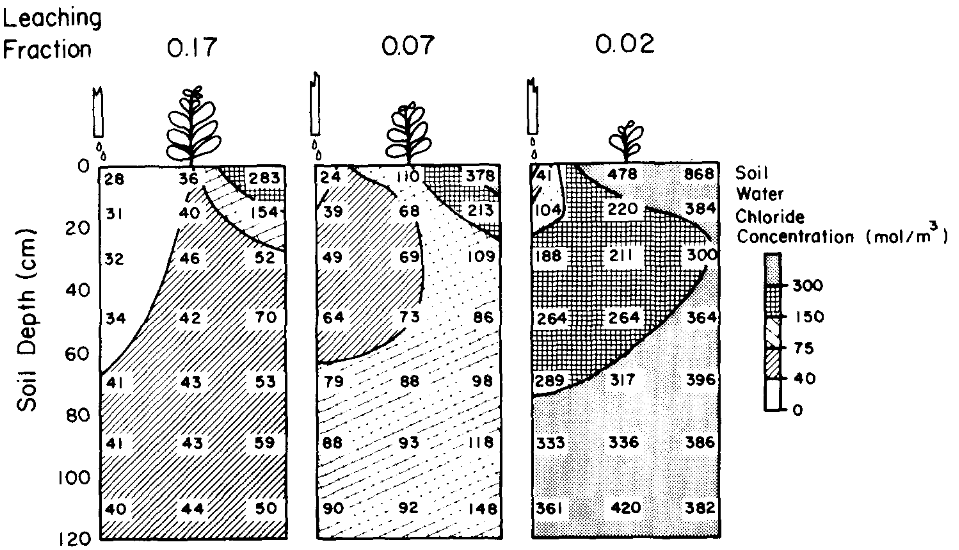

Fig. 4. Pattern of soil-water chloride concentrations for the 0.17, 0.07, and 0.02-leaching treatments. Chloride concentrations given are the average values from soil samples taken during and after the crops.

of accumulation near the soil surface midway between water sources and relatively uniform concentrations below a soil depth of 60 cm because of one-dimensional downward flux below the root zone. Of interest, is the extremely small soil volume for the majority of soil water uptake. The chloride concentration of soil water when half of the applied water has been removed by evapotranspiration is 15.6 mol/m^3 ($ET/D_i = 0.5 = 1 - Cl_i/Cl_d$); chloride concentrations in the first 10-cm soil depth were already above this value.

DISCUSSION

The experimentally determined leaching requirements were 0.10 for barley grain and 0.13 for barley forage (Fig. 1). The models to predict L_r based on an exponential water-uptake distribution pattern (Hoffman and Van Genuchten, 1982) and on the "40—30—20—10" water uptake partition by quarter fractions of the root zone (Rhoades, 1974) indicate L_r values of 0.05 and 0.06 for grain and 0.07 and 0.08 for forage, respectively. Both models require the salinity of the applied water and the crop salt tolerance threshold as input. The threshold values, reported as the electrical conductivity of saturated soil extracts, for barley grain and forage were taken as 8.0 and 6.0 dS/m, respectively (Maas and Hoffman, 1977). Thus, the experimental values of L_r are higher than those predicted by the models by about 0.05.

The threshold values for the other crops determined simultaneously in adjacent plots were 4.9 for cowpea seed and 1.6 dS/m for cowpea forage (West and Francois, 1982) and 1.8 dS/m for celery (Francois and West, 1982). Based on these threshold values, the L_r's based on the model of Hoffman and Van Genuchten (1982) were 0.09 for cowpea seed and 0.23 for cowpea forage. From the model of Rhoades (1974), the L_r's are 0.10 and 0.40 for cowpea seed and forage, respectively. Experimentally, the L_r's were 0.16 for seed and 0.17 for forage. The models predicted too small a L_r for cowpea seed by about 0.07 but overpredicted L_r for forage. If the previously published threshold value for cowpea, 1.3 dS/m (Maas and Hoffman, 1977), had been applied to the models, the predicted L_r's, 0.26 for the exponential model and 0.55 for the 40—30—20—10 model, would have been well above the experimentally determined L_r.

For celery, the L_r was estimated to be 0.20 by the exponential model and 0.32 by the 40—30—20—10 model. The experiment indicated L_r to be 0.14.

Comparisons among the various experimental and predicted values of L_r for cowpea illustrate the sensitivity of both models to the crop's salt tolerance threshold. Unfortunately, most salt tolerance experiments were not designed to establish the threshold. Typically, a wide range of salinity treatments were studied and frequently the only treatment to give full production was the control. In the future more emphasis must be placed on the threshold because it is not only critical for predicting the L_r but this value is of primary importance when selecting irrigation practices to minimize water use without suffering yield loss where salinity is a hazard.

Differences between experimental and predicted values of L_r were larger than found previously (Jobes et al., 1981). However, the differences in irrigation amounts when the experimental and predicted values differ by 0.05 are small. The amount of irrigation required to meet ET and L_r for barley grain is 456 mm [d_i = ET/(1 − L_r) = 410/(1−0.10) = 456 mm]. An increase in L_r from 0.05 to 0.10 would only increase the depth of irrigation by about 25 mm. This difference is not significant in lieu of current accuracies in irrigation applications.

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